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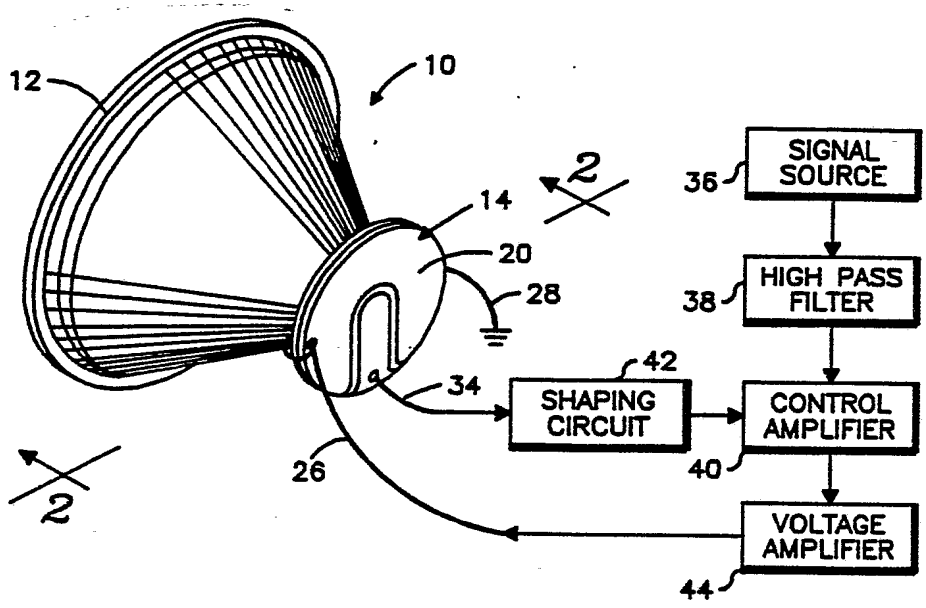
(54) Title: PIEZOELECTRIC LOUDSPEAKER HAVING A FEEDBACK TRANSDUCER



(57) Abstract

In order to smooth the frequency response of a piezoelectric driver (14) which includes two electrodes (20, 22) disposed on opposing surfaces, which driver is mounted to a diaphragm (12), a transducer is formed on one surface of the driver by isolating a portion of the electrode on the surface to form an island (32) electrically insulated from the remainder of the electrode. Upon the application of a signal to the piezoelectric driver (14), the voltage developed at the transducer provides a feedback signal on wire (34) proportional to the acoustic output of the speaker. An acoustic system which incorporates the driver includes a signal source (36), a shaping network (42) and a control amplifier (40) having its gain controlled in response to the feedback signal generated by the transducer as altered by the shaping network.

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PIEZOELECTRIC LOUDSPEAKER HAVING A FEEDBACK TRANSDUCER

Background of the Invention

This invention relates to a piezoelectric loudspeaker in which an integrally formed transducer is excited by the motion of the piezoelectric driver to generate a voltage having an amplitude proportional to the acoustic output of the loudspeaker. This invention is also directed to an audio system utilizing the voltage generated by the transducer as a feedback signal to control the amplitude of the applied audio signal and provide an acoustic output having a predetermined frequency response.

Conventional piezoelectric loudspeakers require considerable mechanical dampening to smooth their frequency response. The dampening increases the moving mass of the speaker which in turn reduces its sensitivity, that is, greater drive power is required to produce a given acoustical output. Thus, the acoustic output level of conventional piezoelectric speakers is usually compromised in favor of a smoother frequency response.

It has generally been impossible to accurately predict the frequency response of any given piezoelectric loudspeaker. It has been difficult, if not impossible in certain situations, to manipulate or alter the natural frequency response of conventional peizoelectric loudspeakers to meet the requirements of specific applications.

United States patent Nos. 3,548,116 and 3,786,202, both to Hugo Schafft, are directed to piezoelectric speakers. In the latter patent, the particular geometry of mounting a truncated diaphragm to the piezoelectric driver and the utilization of a foam rubber member are utilized to smooth the frequency response of the acoustic output.

In U.S. patent No. 3,941,932 to Guido D'Hoogh, a conventional electromagnetic speaker includes a piezoelectric transducer pivotally mounted along two edges to a mounting board which engages the voice coil form. The output of the transducer is degeneratively fed back to the input of an associated amplifier.

Summary of the Invention

It is an object of this invention to provide a piezoelectric loudspeaker having an integrally formed transducer which generates a voltage proportional to the acoustic output of the loudspeaker.

Another object of this invention is to provide an acoustic system utilizing such a loudspeaker wherein the feedback signal developed by the transducer is used to control the gain of an amplifier which drives the loudspeaker to yield an acoustic output having a predetermined frequency response.

In an embodiment of the present invention, a piezoelectric driver including at least two opposing surfaces with electrodes is mounted to a diaphragm. A transducer is formed on one surface of the driver by isolating a portion of the electrode on the surface to form an island electrically insulated from the remainder of the electrode. In response to the application of a signal to the piezoelectric driver, a voltage is developed at the transducer relative to the opposing electrode and provides a feedback signal proportional to the acoustic output of the speaker.

An acoustic system in accordance with an embodiment of the present invention includes a signal source, a shaping circuit and an amplifier having its gain controlled in response to the shaped feedback signal generated by the transducer.

Brief Description of the Drawings

Figure 1 illustrates an embodiment of an acoustic system in accordance with the present invention.

Figure 2 is a cross sectional view taken about line 2-2 of figure 1.

Detailed Description

Referring to figures 1 and 2, a piezoelectric loudspeaker 10 includes a diaphragm 12 and a piezoelectric driver 14. As best seen in figure 2, the illustrative piezoelectric driver 14 is a bimorph consisting of piezoelectric discs 16 and 18 sandwiched between electrodes 20, 22 and 24. A wire connection 26 connects electrodes 20 and 24 together and wire 28 provides electrical connection with the center common electrode 22. The driver 14 may be mounted to the diaphragm 12 such as by means of an adhesive 30 which may consist of an epoxy.

An electrode 32 formed on piezoelectric disc 16 is substantially surrounded by and electrically insulated with respect to electrode 20. Electrodes 20 and 32 may be formed separately on disc 16 or electrode 32 may be formed by etching away or otherwise removing a pattern in electrode 20 to define an island-like electrode 32. As will be apparent from figure 1, electrode 32 provides a radial finger-like projection extending from the center of the driver to its edge. A wire 34 provides an electrical connection to electrode 32.

In the illustrative example of the piezoelectric driver, a driving voltage is applied to the driver by means of wires 26 and 28. The piezoelectric driver vibrates in response to the application of an electric field and thereby sets the diaphragm 12 in motion to produce an acoustic wave. Because the driver is piezoelectric, its movement will induce a voltage across the feedback transducer, i.e., electrode 32 with respect to common electrode 22, that is substantially proportional to the magnitude of the vibratory movement of the driver and hence is proportional to the acoustic wave generated by the speaker 10.

Figure 1 illustrates an audio system for driving speaker 10 which utilizes the voltage developed by electrode 32 as a feedback signal to control the magnitude of the driving signal (voltage) to obtain a predetermined acoustic response. The output signal from signal source 36 is filtered by a high pass filter 38 before being applied as an input to control amplifier 40. The output voltage developed at electrode 34 provides an input to a shaping circuit 42 which provides an input for controlling the gain of control amplifier 40. The output of controlled gain amplifier 40 is amplified by voltage amplifier 44 which is utilized to provide the driving signal to speaker 10.

In the illustrative example of an audio system according to this invention, a high pass filter 38 is used to prevent the passage of signals having a frequency lower than the natural cut-off frequency of speaker 10. If a flat frequency response was the desired acoustic output, the gain of amplifier 40 could be increased excessively in an attempt to produce the same acoustic output for a signal having a frequency below the low frequency cut-off frequency of speaker 10. Of course, a high pass filter 38 is not an indispensable portion of this system since alternative solutions are available,

namely: the gain of amplifier 40 could be limited to a maximum or a signal source 36 could be utilized which does not exceed the frequency limits of speaker 10.

The shaping circuit 42 may consist of a time averaging circuit such as a low pass resistor-capacitor filter to provide a time averaged control signal for controlling amplifier 40. The specific time constant of shaping circuit 42 is dependent upon the degree of smoothing desired. If other than a flat frequency response of the acoustic output is desired, the shaping circuit 42 could also include frequency selective circuitry such as a plurality of band pass filters covering adjacent frequency ranges and a variable attenuator associated with each. Each attenuator is adjusted to produce a control signal corresponding to the band pass frequency range of each filter and having a predetermined amount of attenuation. The control signals from each attenuator are summed to provide a gain control input to amplifier 40.

Amplifier 40 consists of a gain controllable amplifier which is well known in the art. Amplifier 44 may comprise a fixed gain amplifier serving to buffer the output of amplifier 40 and provide additional gain for driving speaker 10. It will be apparent that amplifier 44 may not be needed depending upon the magnitude of acoustic output desired.

When a flat acoustic output versus frequency is desired, the sensed feedback signal at electrode 32, after being smoothed by shaping circuit 42, provides a signal to which the gain of amplifier 40 is inversely proportional. Thus, the gain of amplifier 40 decreases as the amplitude of the feedback signal increases. The effect of such negative feedback is to maintain the signal at electrode 32 at a substantially constant amplitude and hence keeps the acoustic output which is proportional thereto at a substantially constant acoustic output level.

This invention provides numerous advantages. The voltage generated at electrode 34 in response to movement of the piezoelectric driver provides a feedback signal proportional to the acoustic output of speaker 10 which can be utilized to shape the acoustic output of the speaker by controlling the gain of the drive signal applied to the driver. It is important to note that the acoustic output of speaker 10 can be made substantially flat versus frequency by the present invention without dampening the speaker such as by adding selective mass to the diaphragm or driver. Since mechanical dampening need not be added to achieve a desired frequency response, the sensitivity of the actual speaker itself is maximized.

This invention further contemplates other potential applications in which a separate isolated electrode on a piezoelectric driver or transducer is utilized. For example, such an electrode permits the simultaneous utilization of a piezoelectric transducer as both a speaker and microphone in which the electrical input to the speaker and the output from the microphone are electrically isolated.

Although an illustrative embodiment of the present invention has been shown and described, it will be apparent to those skilled in the art that other embodiments within the scope of this invention as defined by the attached claims are possible. For example, a monoroph could be utilized as the piezoelectric driver instead of the illustrated bimorph. Also, other shapes and configurations of feedback generating electrodes could be employed. More than one feedback electrode could be utilized on a given surface of a piezoelectric element and electrodes on various surfaces could be used.

What is claimed is:

1. A piezoelectric acoustic transducer comprising;
at least one piezoelectric disc;
first and second electrodes disposed on opposite surfaces of said disc; and
a sensing electrode disposed on a surface of said disc and being electrically separate from said first and second electrodes, said sensing electrode developing a voltage substantially proportional to movement of said disc.

2. The transducer of claim 1 wherein said sensing electrode is coplanar with said first electrode.

3. The transducer of claim 2 wherein said sensing electrode extends radially inward from near the periphery of said disc to substantially the center of said disc.

4. The transducer of claim 1 further comprising a second piezoelectric disc having one surface contiguous with said second electrode and a third electrode disposed on the other surface of said second disc, said first and third electrodes being connected electrically together.

5. In an audio system having means for amplifying an audio signal and a piezoelectric loudspeaker that receives the amplified audio signal, the improvement comprising:

said loudspeaker including a piezoelectric driver having a sensing electrode which develops a voltage substantially proportional to the acoustic output of said loudspeaker; and

means for controlling the gain of said amplifying means in response to said voltage so that the gain of said amplifying means is controlled to produce a predetermined acoustic output from said loudspeaker.

6. The audio system of claim 5 further comprising means for filtering said audio signal prior to its amplification by said amplifying means so that only audio signal frequencies within the frequency response range of said loudspeaker are coupled to said amplifying means.

7. The audio system of claim 5 wherein said piezoelectric driver includes a disc of piezoelectric material and first and second electrodes disposed on opposite surfaces of said disc, said sensing electrode being substantially coplanar with said first electrode.

8. The audio system of claim 7 wherein said sensing electrode extends radially inward from near the periphery of said disc to substantially the center of said disc.

9. The transducer of claim 8 further comprising a second piezoelectric disc having one surface contiguous with said second electrode and a third electrode disposed on the other surface of said second disc, said first and third electrodes being connected electrically together.

10. A method for generating a predetermined acoustic output over a range of frequencies with a piezoelectric loudspeaker comprising the steps of:

applying an audio drive signal across first and second electrodes disposed on a piezoelectric disc;

developing a control voltage substantially proportional to the acoustic output of the loudspeaker between a sensing electrode disposed on one side of the disc and the one of the first and second electrodes disposed on the opposite side of the disc; and

controlling the magnitude of the audio drive signal in response to the control voltage to modify the natural acoustic output of the loudspeaker to the predetermined acoustic output.

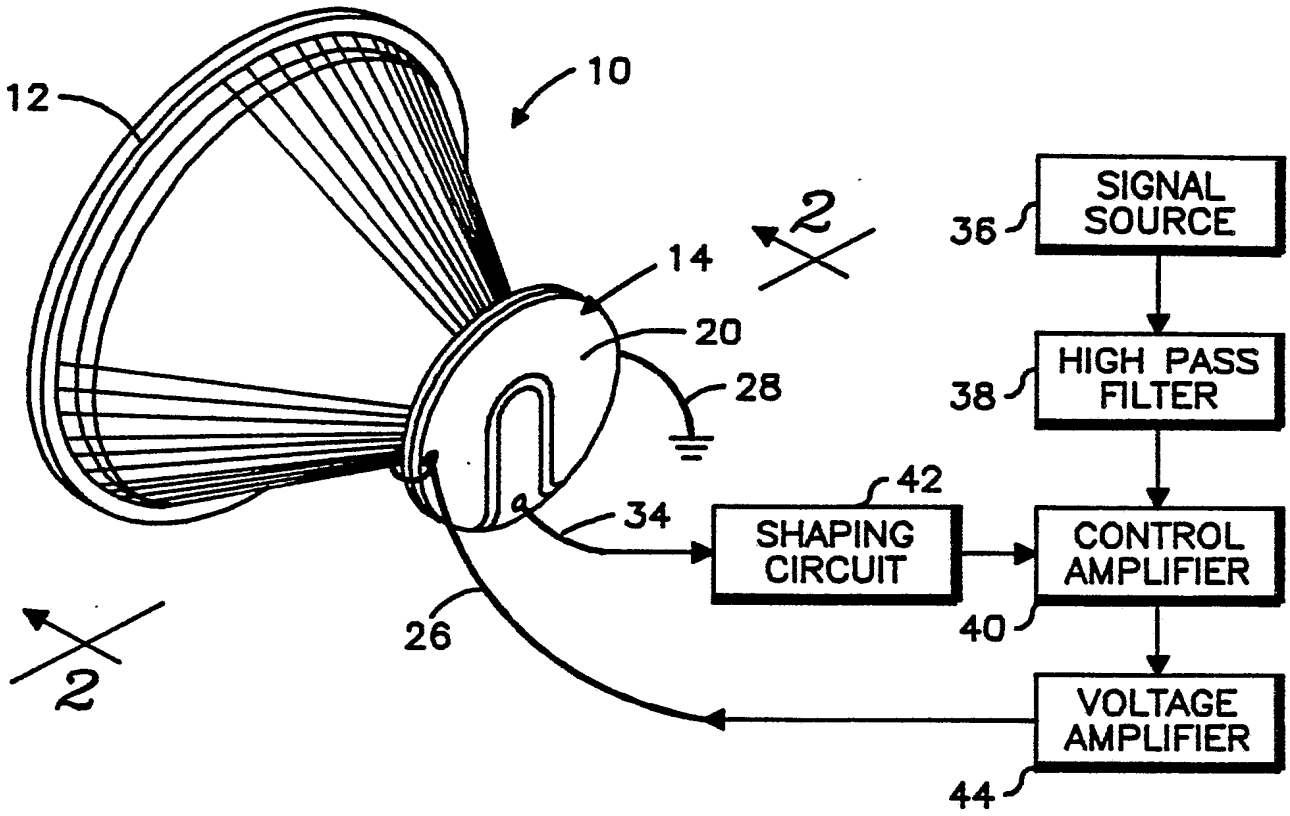
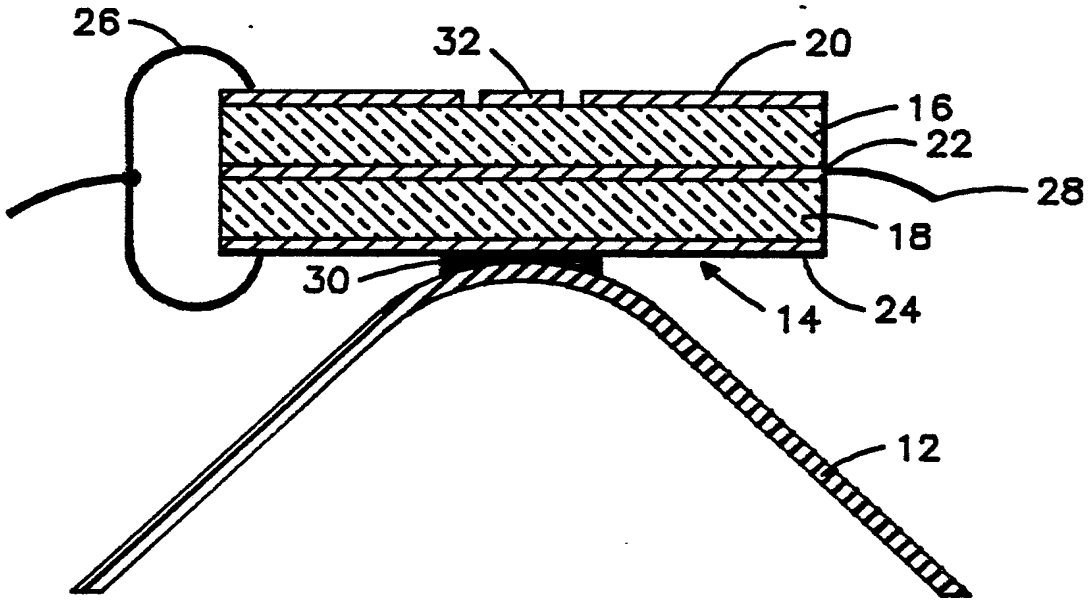

12
10
2
14
20
28
2
26
SIGNAL SOURCE
36
HIGH PASS FILTER
38
42
34
SHAPING CIRCUIT
CONTROL AMPLIFIER
40
VOLTAGE AMPLIFIER
44

Fig. 1


26
32
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16
22
28
18
30
14
24
12

Fig. 2

INTERNATIONAL SEARCH REPORT

International Application No PCT/US85/01469

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [3]

According to International Patent Classification (IPC) or to both National Classification and IPC

Int. Cl.[4] H04R 3/00
U.S. CL. 381/96

II. FIELDS SEARCHED

Minimum Documentation Searched [4]

Classification System	Classification Symbols
U.S.	381/96,111; 179/110A; 367/163,180; 310/324

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [5]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [14]

Category *	Citation of Document, [16] with indication, where appropriate, of the relevant passages [17]	Relevant to Claim No. [18]
X	US, A, 3,937,887, Miller, 10 February 1976	16
X	US, A, 4,374,377, Saito et al., 15 February 1983	1-14,17-20
X	US, A, 4,395,588, Franssen, Deceased et al 26 July, 1983	16
X	US, A, 4,429,247, Feldman, 31 January 1984	1-14,17-20
X	US, A, 4,451,710, Taylor et al. 29 May 1984	15-20
X,P	US, A, 4,475,014, King, 02 October 1984	5-14,19
X	US, A, 4,283,605, Nakajima, 11 August 1981	5-14,19

* Special categories of cited documents: [15]

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IV. CERTIFICATION

Date of the Actual Completion of the International Search [2]	Date of Mailing of this International Search Report [2]
22 August 1985	19 SEP 1985
International Searching Authority [1]	**Signature of Authorized Officer [20]**
ISA/US	Forester W. Isen